NOTICING STUDENT MATHEMATICAL THINKING IN THE COMPLEXITY OF CLASSROOM INSTRUCTION

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Noticing students' mathematical thinking is recognized as a key element of effective instruction, but novice teachers do not naturally attend to and make sense of student thinking. We describe a design experiment in which prospective teachers were engaged in analysis of minimally edited classroom video in order to support their ability to notice important student mathematical thinking within the complexity of classroom instruction. We discuss evidence of prospective teachers' learning in five iterations of the intervention, including the extent to which they developed a focus on students' mathematics, changes in the ways they discussed that mathematics, and the extent to which they focused on instances of student mathematics that had potential to be capitalized on to support student learning. Aspects of the intervention that seemed to support teachers' noticing are discussed, as well as future directions for the work.

Keywords: Classroom Discourse; Design Experiments; Teacher Education-Preservice

Research has shown that a key distinction between novice and expert teachers is their ability to notice what is important in complex classroom situations (Berliner, 2001). Because teachers' use of student thinking has been identified as a key element of effective instruction (e.g., NCTM, 2014) and has been linked to increased student learning (Fennema, Carpenter, Franke, et. al, 1996), one particularly important focus of teacher noticing is student mathematical thinking. However, research suggests that teachers, particularly novices, do not naturally attend to and make sense of student ideas (Jacobs, Lamb, & Philipp, 2010). Fortunately, noticing student mathematical thinking is a skill that can be learned (e.g., Jacobs, et al., 2010; Sherin & van Es, 2005) and has thus become a focus in many teacher preparation programs.

Many recent prospective teacher noticing interventions, focused on what has been termed *professional noticing of children's mathematical thinking* (Jacobs, et al., 2010), have supported noticing through analysis of student written work (e.g., Fernández, Llinares, & Valls, 2013; Haltiwanger, & Simpson, 2014) or short video excerpts of one-on-one student interviews (Schack, Fisher, Thomas, et. al, 2013). This work has also typically focused on student thinking related to specific mathematical content, for example, proportional reasoning or early numeracy. Evidence across these interventions suggests that prospective teachers' noticing skills can be successfully developed in "environment(s) in which the number of salient features was limited and, therefore, a manageable focus for discussions" (Schack, et. al, 2013, p. 395). Mathematics classrooms, however, are not limited in the scope of what might be noticed. This raises questions of whether prospective teacher noticing can be supported in a more complex context that simulates that of classroom noticing, and whether prospective teachers' professional noticing skills can be developed using classroom artifacts that include a range of mathematical foci.

Evidence suggests that using classroom video as a medium to promote professional noticing might be enhanced by providing a way to scaffold teacher noticing, such as targeted questions or a framework (e.g., Roth McDuffie, Foote, Bolson, et al., 2014; Santagata, 2011). Santagata (2011), for example, found that posing targeted questions to focus teachers on the relationship between a teacher's actions and students' learning of mathematics supported teachers in providing more in-depth analyses of these interactions. Similarly, Roth McDuffie and colleagues (2014) found that providing carefully designed prompts supported prospective teachers in higher level noticing,

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including making connections between key components of teaching and learning. In short, research suggests that specific prompts support the noticing of what is valued within classroom interactions. This study builds on this work by examining the use of an explicit analytic framework to scaffold prospective teachers' mathematical noticing.

In this study, we examine the effects of an intervention designed to promote prospective teachers' noticing of student mathematics that could be used by a teacher to support students' understanding of the mathematics. In particular, we focus on the following research questions: (a) In what ways does prospective teacher noticing change as a result of the intervention?; and (b) How do variations in the viewing framework appear to affect prospective teacher noticing?

Theoretical Framework

Consistent with Jacobs and colleagues (2010), we aim to promote the *professional noticing of [student]'s mathematical thinking*. We follow their definition of this practice to include three interrelated skills: (a) attending to student thinking, (b) interpreting what students are saying mathematically, and (c) deciding how to respond. In this study, we focus on just the first two components of the practice. Our choice of this noticing focus stems from its close connection to our goal of helping prospective teachers learn to enact *ambitious teaching* (Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010)—"deliberately responsive and discipline-connected instruction" (p.130) that supports all students in developing deep understanding of mathematics.

Although our work is firmly grounded in the noticing of student mathematics, we also take the perspective that not all instances of student mathematical thinking have the same potential to enhance student learning. Thus, we focus specifically on noticing instances of student thinking that have significant potential to be used during the lesson to support the learning of important mathematics. In particular, we draw on Leatham, Peterson, Stockero, and Van Zoest's (2015) definition of **M**athematically Significant Pedagogical **O**pportunities to Build on **S**tudent **T**hinking [MOSTs] as occurring at the intersection of three characteristics: (a) student mathematical thinking, (b) significant mathematics, and (c) pedagogical opportunity. The MOST analytic framework uses two criteria to determine whether an instance of student thinking embodies each of these characteristics. For student mathematical thinking the criteria are that there is sufficient evidence to reasonably infer the student mathematics and that one can articulate a mathematical point closely related to this student mathematics. The significant mathematics criteria are that the mathematical point is appropriate for the mathematical development level of the students and is central to mathematical goals for their learning. The pedagogical opportunity characteristic requires that the student mathematics creates an opening to build on student thinking to help develop an understanding of the mathematics and that the timing is right to take advantage of the opening. Instances that satisfy all six criteria, and thus all three required characteristics, are MOSTs (see Leatham et al., 2015 for more details). In this study, the MOST analytic framework was used as a tool to focus participant noticing.

Methodology

The Intervention

The participants in the study were 17 prospective mathematics teachers (PTs) enrolled in an early field experience course between fall 2011 and fall 2014. They participated in the study in five cohorts, each with three to four PTs. Each PT was assigned to observe a local, experienced secondary mathematics teacher's classroom. Participants recorded videos of mathematics lessons in these classrooms on a rotating basis; over the course of each semester, efforts were made to collect video from a range of grade levels with varied mathematical topics. The instructional portions of the classroom video were left mainly unedited for analysis, although portions in which students could not

easily be heard were removed. The PTs and researchers used the Studiocode (SportsTec, 1997-2015) video analysis software to individually analyze one video each week, marking mathematically important moments a teacher should notice in the classroom. The PTs included a description of why they chose each moment. The researchers met weekly to agree on instances that were MOSTs in the video and to discuss the instances PTs had identified as important, including which instances would be discussed at a weekly group meeting among the PTs and researchers. These group meetings were facilitated by the first author and focused on building PTs' skills in noticing mathematically important moments.

Because the intervention was conceived as a design experiment (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), the specific scaffolding activities varied by semester. All of the PTs were initially prompted to identify *mathematically important moments that a teacher should notice during a lesson*, with the definition of this construct left open ended to provide baseline data for PT noticing. All of the cohorts except cohort 5co-developed labels in the weekly group meetings to describe and categorize types of mathematically important moments. These labels drew on Stockero and Van Zoest's (2013) pivotal teaching moment categories, but the categories were not made explicit to the PTs. After the creation of these labels, PTs assigned labels to moments they marked in subsequent videos. Each cohort was introduced to a variation of the MOST framework at some point during the semester. This framework evolved over the four years of the study, so cohorts 1 and 2 used a general version of the framework in which the MOST criteria were only loosely defined in terms of student thinking, important mathematics, and pedagogical opportunity. Cohorts 4 and 5 used the most explicit, analytical version of the framework as defined in Leatham and colleagues (2015). The MOST framework was introduced to the first four cohorts five to six weeks into the semester and to cohort 5 two weeks into the semester. After the introduction of the framework, PTs were expected to focus on moments in the videos that were MOSTs, as defined by the version of the framework available at the time. Cohort 5 was pushed to most explicitly discuss each characteristic of the framework.

Data Collection and Analysis

The study data was the PTs' video analyses and video recordings of the weekly meetings. To analyze how the PTs' noticing changed during the intervention, we analyzed the video instances the PTs had marked and their reasoning. APT's written description of an instance received the most weight. When available, aPT's label and what (s)he said about the instance in the meeting were also considered. To minimize the possibility that PTs influenced each other's thinking, the meeting commentary received more weight if a PT was the first to speak about an instance.

The unit of analysis was a PT-identified instance. Drawing on frameworks used in previous research (Stockero, 2008; van Es & Sherin, 2008), each instance was coded for the agent of the PT noticing and the level of specificity with which the mathematics was described. If there was any student focus in an instance, an additional code was assigned to describe the nature of the PT's noticing of the student(s). Figure 1 gives the coding categories, definitions and codes.

Coding Categories	**Description**	**Codes**
Agent	Who or what was the focus of the noticing*	Teacher (T), Teacher/Student (T/S), Student/Teacher (S/T), Student Group (Sg), Individual Student (Si), Math (M)
Math Specificity (MS)	Whether and how the mathematics is discussed	Non-math (NM), General Math (GM), Specific Math (SM)
Nature of Noticing (NoN)	For instances with some student focus, what about the students was attended to	Affective Interaction, General Understanding, Mathematical Interaction, Noting Student Math (NSM), Analysis of Student Math (ASM)
*Student-teacher interactions are coded as teacher/student if the teacher is the primary focus and student/teacher if the		

student is the primary focus

Figure 1:Coding Framework

To give a sense of some of the key codes that we will discuss, consider the three instances in Figure 2. These all focus on the same instance of an individual student's thinking so were all coded as Si for the agent. Although instance 2 is focused on a student mathematical question, we have no idea what the related mathematics is, so it was coded GM for math specificity. The mathematics is discussed in a much more specific way in instances 2 and 3, however, so these were coded as SM. Instances 1 and 2 describe the important student mathematics, but do not go beyond this, so were coded as a NSM focus. Instance 3 on the other hand, is making sense of why the student asked the questions she did, so was coded as an ASM focus.

	Description of Instance	**MS**	**NoN**
	I think that this is a very good question that is necessary to further learning (making examples similar). The student describes her question in depth to infer her thinking.	GM	NSM
	Student is curious as to why they need to divide by the determinant to find the inverse [matrix] in this example, but not in the previous example.	SM	NSM
	[S]he does not know why we are multiplying by 1/2 in one example and not the other. The student does not understand that they have to multiply by 1/det[A], probably because the multiplication of 1/det[A] was not shown in the previous example because the det[A]=1. We {we]re multiplying the matrix [d -b –c a] by 1, which is trivial. The students should understand that if two matrices multiplied together give the identity, that they are inverses of each other.	SM	ASM

Figure 2:Coding Examples

In the analysis process, each PT-identified instance was individually coded by either two or three researchers. The researchers then met to reconcile the coding; when there was disagreement about one or more codes for an instance, the instance was discussed among the group until agreement was reached. In cases where two researchers were unable to reconcile their coding, the third researcher was brought into the discussion to help resolve any coding differences.

Results

The goal of the intervention was to promote the noticing of instances of student mathematics that have the potential to be capitalized on during a lesson to support student learning. Thus, our analysis focused on the extent to which we were able to promote such noticing. We discuss both changes in the PTs' noticing as a result of the intervention, as well as the extent to which the PTs met our "target" for noticing: individual students, specific mathematics, and noting or analyzing student mathematics. In this discussion, *baseline* refers to the PTs' noticing in the first two videos each semester, before there was any attempt to focus their noticing. *Final* refers to the noticing in the last four videos each semester—an indication of the PTs' most refined noticing. We use four videos to report the final noticing because most of the PTs noticed significantly fewer instances in these later videos. In fact, PTs noticed an average of 8.8 instances per video early on, and less than half that amount (3.75 instances/video) in the final four videos, an indication of becoming more selective about the instances deemed important to notice.

Agent

Table 1 shows the percent of PT noticing focused primarily on students (coded Sg, Si, or S/T), primarily on the teacher (T or T/S), and on the mathematics itself in the baseline and final data. At the start of the intervention, a significant percent of the PTs' noticing was focused primarily on the teacher in the video, and to a lesser extent, on the mathematics itself. This non-student focused

noticing accounted for between 25% and 81.2% of the baseline noticing. Except for cohort 1, 51.0% or fewer of the instances noticed by the PTs in the baseline data had a primary student focus. At the end of the intervention, however, the majority of each cohort's noticing was focused on the students in the video, ranging from 85.5% to 100% of instances.

Table 1: Participant Noticing by Primary Agent

		Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Primary Student Focus	Baseline	75.0%	46.7%	51.0%	18.8%	28.4%
	Final	88.9%	100.0%	90.0%	98.3%	85.5%
Primary Teacher Focus	Baseline	22.7%	33.3%	42.9%	59.4%	62.5%
	Final	9.5%	0.0%	6.0%	1.7%	14.5%
Math Focus	Baseline	2.3%	20.0%	6.1%	21.9%	9.1%
	Final	1.6%	0.0%	4.0%	0.0%	0.0%

Although the primary focus on students was encouraging, we were particularly interested in the extent to which PTs focused on individual students and their mathematics. Thus, we further analyzed the subset of instances with a primary student focus to determine whether the PTs' focus in these instances was on individual students, groups of students, or student-teacher interactions (Table 2). At the start of the intervention, each cohort's student-directed noticing was either focused mainly on groups of students (cohorts 1, 2, and 5) or on student-teacher interactions (cohort 4); cohort 3's noticing was evenly split between the two. With the exception of cohort 1, the PTs' final noticing was primarily focused on individual students (79.7% to 90.3% of instances), indicating that the intervention was successful in focusing the PTs on what individual students were saying or doing during the lesson.

Table 2: Primary Student Noticing

		Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Individual Students	Baseline	39.4%	21.4%	16.0%	38.9%	4.0%
	Final	37.5%	90.3%	84.4%	79.7%	85.1%
Groups of Students	Baseline	51.5%	57.1%	44.0%	16.7%	68.0%
	Final	8.9%	9.7%	11.1%	6.8%	8.5%
Student/Teacher	Baseline	9.1%	21.4%	40.0%	44.4%	28.0%
	Final	53.6%	0.0%	4.4%	13.6%	6.4%

Focus of Noticing

Instances with any student focus (coded Si, Sg, S/T and T/S) were also coded to characterize what about the students the PTs had noticed. As a reminder, the goal was to focus PTs' attention on what students were saying mathematically, so the target was noting or analyzing the student mathematics, with analyzing deemed to be the higher-level of the two foci. Due to space constraints, we discuss just these two noticing foci.

There was a wide difference in the percent of the student-focused instances coded as either noting or analyzing student mathematics for each cohort in the baseline data (Table 3). The first two cohorts had a total of 47.5% and 46.4% of such instances coded with one of these foci, while the latter three cohorts had a significantly lower percent, ranging from only 2.3% to 20.4%. In the baseline data, only cohort 2 demonstrated any analyzing; this was all attributable to just one PT. All of the cohorts increased their noticing with these two foci. In fact, with the exception of cohort 1, the final data shows that 85.5% or more of the PTs' student-centered noticing was coded as noting or analyzing

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student mathematics, with noting instances accounting for the majority of the instances for cohorts 2, 3 and 4, and a more even split between noting and analyzing (47.3% and 38.2%, respectively) for cohort 5. Cohorts 2 and 5 demonstrated the highest percentage of analyzing, but again, cohort 2's analyzing was largely attributable to one PT. Cohort 5's percent of analyzing was not only the highest among all cohorts, but was also more consistent among the PTs in the cohort. Collectively, the data suggests that the intervention was successful not only in focusing the PTs' attention on students, but also on the important mathematics that came from these students in the lessons. More specific versions of the framework were generally more effective in supporting noticing. The higher percent of analysis by the last cohort also suggests that providing a framework earlier in the intervention and engaging PTs in a more structured use of the framework better supported noticing than earlier iterations of the intervention.

Table 3: Participant Student-Centered Noticing Focus

		Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Noting Student Math	Baseline	47.5%	32.1%	20.4%	15.6%	2.3%
	Final	59.0%	76.7%	78.0%	89.8%	47.3%
Analyzing Student Math	Baseline	0.0%	14.3%	0.0%	0.0%	0.0%
	Final	1.6%	20.0%	8.0%	8.5%	38.2%

Specificity of Mathematics

The specificity of the PTs' noticing indicates whether and in what level of detail the mathematics in an instance was discussed. Non-mathematical noticing was present in the baseline data for all cohorts and was most prevalent for cohort 5, with 39.8% of their noticing focused on non-mathematical features of classroom interactions (Table 4). There was no non-mathematical noticing present in the final data, however. Perhaps surprisingly, most cohorts discussed the mathematics in a specific way more than half of the time from the start (between 52.5% and 75% of instances), although cohort 5 only did so 29.5% of the time in the baseline data. All of the cohorts maintained or became more specific in their discussion of the mathematics through the intervention, with the final three cohorts most consistently discussing the mathematics in a specific way in the final data and cohort 5 showing the most significant change in specificity. This again suggests the benefit of a more explicit analytic framework.

Table 4: Specificity of Participant Noticing

		Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Non-math	Baseline	15.0%	10.7%	2.0%	3.1%	39.8%
	Final	0.0%	0.0%	0.0%	0.0%	0.0%
General Math	Baseline	32.5%	14.3%	38.8%	26.0%	30.7%
	Final	24.6%	26.7%	12.0%	13.6%	5.5%
Specific Math	Baseline	52.5%	75.0%	59.2%	70.8%	29.5%
	Final	75.4%	73.3%	88.0%	86.4%	94.5%

Noticing of MOSTs

An additional measure of PT learning was whether they became better able to identify instances of student mathematics that had potential to be used to support student learning of mathematics—that is, instances that were MOSTs. Table 5 gives the percent of the instances that PTs marked that coincided with instances the researchers identified as MOSTs. As seen in the table, all of the cohorts

increased in the percent of moments that aligned with the researchers' moments, but the data needs to be interpreted with caution. Ongoing analysis is focused on determining whether the PTs talked about these instances in a way that indicates they were focused on the student mathematics, rather than for some other reason.

Table 5: Participant Noticing of MOSTs

	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Baseline	60.0%	32.1%	44.7%	25.0%	17.0%
Final	86.9%	66.7%	68.0%	67.2%	67.3%

Discussion and Conclusions

The findings of this study add support to a growing body of research demonstrating that it is feasible to develop prospective teachers' professional noticing skills. In fact, we developed these skills at the start of a teacher preparation program, when the prospective teachers had very little knowledge of students to draw upon. Key differences between this and many other interventions are that the noticing intervention used longer unedited classroom video recorded in local teachers' classrooms and focused on a range of mathematical topics, depending on the topics of the recorded lessons. Thus, these findings suggest that there may not be a need to narrow either the scope or length of classroom artifacts used to develop noticing skills (i.e., use short transcripts or video clips), nor the mathematical focus of the noticing activities.

The data also showed a general trend that when a more explicit analytic framework was provided, the PTs came to discuss the mathematics in a more specific way, and more often noted and analyzed what the students in the video were saying mathematically. Although the total percentage of instances in which the PTs noted or analyzed student mathematics was a bit lower for cohort 5, they and cohort 4 showed the greatest increase in these foci from beginning to end of the intervention. Furthermore, cohort 5 reached the analyzing level in 38.2% of all instances in the final videos—significantly more than any other cohort. These findings suggest that, although using even a loosely defined framework can support prospective teacher noticing (cohorts 1 and 2), using a more structured framework can significantly improve the outcomes of a noticing intervention. The fact that cohort 5 was given the framework earlier and was prompted to use the framework in a more structured way likely also enhanced their learning, although additional analysis is necessary to confirm whether this is the case.

Although the findings are noteworthy, there are still open questions that need to be addressed. For instance, we do not yet know how the participants' interactions with each other during the weekly meetings or the facilitation of these meetings supported the PTs' noticing, nor have we yet examined the PTs' proposed teacher responses to identified moments. Ongoing work is also focused on understanding how the noticing skills developed during this intervention transfer to noticing student ideas during the PTs' own instruction. Addressing questions such as these holds potential for helping novice teachers learn to enact the type of student-centered instruction the field has been striving to achieve (e.g., NCTM, 1989; 2014).

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